embodiments of the invention. FIG. 44 shows the VHF only payload, FIG. 45 shows dual VHF and UHF downlink modules and FIG. 46 shows a combined VHF and UHF payload diagram.

FIG. 47 shows how satellites transfer data from an Equatorial to an inclined orbit via a crosslink through a relay station.

FIGS. 48, 49 and 50 are diagrams showing satellite footprints for satellites orbiting at 800 km, 1,100 km and 1,852 km altitudes.

FIGS. 51, 52 and 53 portray mean and maximum response times for satellites orbiting at 800 km, 1,100 km and 1,852 km altitudes.

FIG. 54 shows schematically a radio beacon system for monitoring sea environment and tracking data with deployed buoys transmitting data through the satellite-to-ground terminal links of this invention.

FIG. 55 is a schematic depiction of an interactive television system using a return link from a viewer to a TV broadcaster through the satellites of this invention.

FIG. 56 depicts the return link from a viewer of a satellite TV broadcast through the satellite-to-ground terminal links of this invention and terrestrial based telephone networks.

FIG. 57 is a schematic diagram showing a method of providing connectivity to movable devices or devices with low rate data inside a building which shields the user's radio signal from the satellite.

DETAILED DESCRIPTION OF PREFERRED & ALTERNATIVE EMBODIMENTS

I. An Equatorial Constellation of Satellites

FIG. 1 is a schematic view 10 of a constellation of six satellites 12 utilized in one of the embodiments of the present invention. In the text that follows, the term "constellation" refers to the entire group of satellites 12. A complete implementation of the invention which incorporates the constellation as well as equipment such as relay stations on or near the Earth's surface is described by the terms "system" or "network".

The satellites 12 shown in FIG. 1 operate in an orbit 14 which lies in the same plane as the Earth's Equator 16. In one embodiment, the satellites 12 are equally spaced around an Equatorial orbit at an altitude of 1,852 kilometers. In this specification, constellations having different numbers of orbital planes and various populations of satellites 12 in those orbital planes are disclosed. While a variety of numbers of orbit planes and satellites may be employed to implement the present invention, the reader should understand that the invention embraces any configuration that does not utilize geo-stationary spacecraft flying in orbits at an altitude of approximately 23,000 miles, except for using geo-stationary spacecraft as a communications link.

FIG. 1 shows two lines of latitude, indicated by reference characters 18 and 20, on the surface of the Earth. These lines represent 30 degrees North and 30 degrees South, respectively. The region of the Earth's surface bounded by these lines of latitude 18 and 20 are within the service areas of the satellites 12 in the Equatorial orbit 14. FIG. 2 reveals an illustration 22 of one embodiment of invention using fourteen equally spaced satellites 12 operating in Equatorial orbit 14. The preferred embodiment of the present invention may utilize from six to fourteen satellites 12 in Equatorial orbit 14.

FIG. 3 is a schematic depiction of a satellite 12 that may be employed in one of the embodiments of the invention. This satellite 12 comprises a body 24, solar panels 25, a pair of helical antennas 26 and inter-satellite link antennas 28.

FIGS. 4 and 5 are maps 30 and 32 showing regions of the Earth which lie between 30 degrees North and 30 degrees South latitude.

FIG. 6 is a schematic diagram which exhibits relay stations 34 located on ground within 30 degrees of the Equator. These Equatorial relay stations 34 are capable of communicating with the satellites 12 in the Equatorial orbit via uplinks 35a and downlinks 35b.

FIGS. 7, 8 and 9 are maps 36, 44 and 48 that portray footprints 38, 46 and 50 which result from radio beams directed toward the Earth by satellites 12 flying in Equatorial orbit 14 at an altitude of 1,852 km. The footprints 38, 46 and 50 are produced by constellations of six, eight and fourteen satellites 12, respectively. Degrees of latitude are shown along the vertical axis, and are delineated by reference character 40, while degrees of longitude are shown along the horizontal axis, and are indicated by reference character 42.

FIG. 10 is a schematic representation 52 of satellites 12 in Equatorial orbit 14 which work in combination with relay stations 34 on the Earth E to send data over uplinks 35a and downlinks 35b. FIG. 11 is a diagram 54 which shows satellites 12 communicating over inter-satellite links 55. FIG. 12 reveals a diagram 56 of satellites 12 in Equatorial orbit 14 using a combination of ground relay stations 34 and inter-satellite links 55 to relay data. Any combination of ground relay stations 34 and inter-satellite links 55 may be employed to speed a message throughout a particular orbital plane. This novel use of relay stations 34 and inter-satellite links 55 enables the system to accelerate the delivery of a message payload to its destination instead of waiting for the satellites 12 in the orbit plane 14 to precess around the Earth to its point of delivery.

II. Combined Constellation Including Equatorial, Polar & Inclined Orbits

FIG. 13 reveals an illustration 58 of satellites 12 which occupy both Equatorial and polar orbits 14 and 60. Relay stations on the ground situated in both the Equatorial and polar regions 34 and 61 are used to convey messages across orbits.

FIG. 13 shows an embodiment which uses both Equatorial and polar orbits 14 and 60. In the discussion that follows, relay stations referred to as "Equatorial relay stations" are generally located within thirty degrees of the Equator. "Polar relay stations" are those situated near the North or South Poles. "Middle-latitude relay stations" are those which provide uplinks and downlinks that are not handled by either the Equatorial or polar relay stations.

The embodiment shown in FIG. 13 offers a system for transmitting a message through a series of Equatorial, polar and middle-latitude relay stations 34, 61 and 65. A first satellite 12 traveling in the Equatorial orbit 14 receives and stores a message from a first Equatorial relay station 34. This communication as indicated as an uplink transfer TR1 in FIG. 13. The first satellite continues eastward in its Equatorial orbit after this first uplink, and then sends the message down to a second Equatorial relay station 34 via downlink TR2. Once the satellite in polar orbit passes within range of this second Equatorial relay station, an uplink TR3 occurs, and a satellite heading for the North Pole carries the message Northward. Once this satellite in polar orbit passes over a polar relay station 61, downlink TR4 drops the message back to Earth. The same polar relay station 61 then sends the message up in transfer TR5 to a satellite flying south in a neighboring polar orbit 60. This Southbound satellite finishes the store-and-forward relay process by dropping the message to middle-latitude relay station 65 via downlink TR6. Any of these relays could be accelerated by intermediate caroms to other ground relay stations or by using inter-satellite links 55.

FIGS. 14 and 15A supply diagrams 62 and 64a of combined fleets of satellites comprising both Equatorial and inclined orbits 63. The inclined orbits 63 shown in FIG. 14 are inclined sixty degrees to the Equator, while those shown in FIG. 15A are inclined fifty degrees to the Equator. FIG. 15A is a perspective diagram of another constellation of satellites 12 which includes Equatorial orbits 14 and orbits inclined at fifty degrees to the Equator and in which the relay stations 34 are distributed internationally in a pattern of locations on the Earth which maximize coverage and minimize time to forward messages and data between any two user terminals. While the present invention may use any combination of Equatorial and inclined orbits, orbits inclined from fifty to sixty degrees from the Equator have been selected for the preferred embodiment. FIG. 15B presents yet another depiction 64b of a mixed constellation comprising Equatorial, polar and inclined orbits.

FIG. 16 illustrates the elevation angle 68 of approximately five degrees which is required for reliable operation of the present invention. The elevation angle 68 is the angle measured from the local horizon at a terrestrial terminal such as a relay station 34 up to the region of the sky where the relay station 34 will be capable of communicating with one of the satellites 12 in the constellation.

FIG. 17 is a graph of latitudinal reach versus altitude from an Equatorial orbit to a fifteen degree elevation angle.

III. Earth Segment Description

Distributed Relay Stations

As shown in FIG. 15A, a preferred embodiment 64a of the present invention employs approximately ten to one hundred "distributed" relay stations 34. The relay stations 34 are distributed internationally in a pattern of locations on the Earth E which maximize coverage and minimize time to forward messages and data between any two user terminals 212, as shown in FIG. 19. The relay stations are linked together in several ways as discussed below under the heading "Communication Links and Protocols".

FIG. 18 shows one of four orbital planes 210 which are inclined at fifty degrees to the Equator. In this embodiment, six equally spaced satellites 12 are placed in each circular, orbital plane 210 at an altitude of 950 kilometers (km). In this embodiment, there is no overlap of the satellite 12 radio beam footprints between satellites 12 in the fifty degree inclined orbits. Ground control of frequency assignments will prevent interference between satellites in these orbits and satellites in Equatorial orbit 14.

IV. Communications Links and Protocols

The present invention comprises a satellite system that will provide store-and-forward coverage of virtually all locations on the Earth's surface. The following discussion is based on one preferred embodiment 64a (refer to FIG. 15A) in which the constellation includes twenty-four satellites 12 in four orbital planes 210, equally spaced around the Equator and inclined at 50 degrees. In this preferred embodiment 64, each orbital plane 210 contains six equally spaced satellites in a circular orbit at an altitude of 950 km. While the detailed information in respect of power requirements, surface footprints of each satellite's radio beams, and the like are specific with respect to this embodiment, it will be appreciated by those skilled in the art that the methods and apparatus described are equally applicable to other embodiments having different constellations or orbital planes.

User terminals 212 are distributed randomly, primarily in portions of the Earth E which are inhabited. In FIG. 19, a primary method of communication between subscribers operating user terminals 212 is shown. A subscriber communicates with a satellite 12 by means of a user terminal-satellite uplink (TSU) 214. The satellite stores the message and forwards it at a later time to another subscriber by means of a user terminal-satellite downlink (TSD) 216. To reduce the time for delivery, the satellite is able to send the message to a relay station 34 through a relay station-satellite downlink (RSD) 35b. The relay station 34 retransmits the message to a second satellite 12 in an orbit 210 which will more quickly pass nearby to the addressee. The retransmission is through a relay station-satellite uplink (RSU) 35a. The second satellite 12 at a later time sends the message to the addressee through a user terminal-satellite downlink (TSD) 216.

In FIG. 19, relay station 34 is a message-forwarding terminal, since it holds a message from a subscriber obtained by means of a relay station-satellite downlink 35b transmission. The relay station 34 may hold this message until another satellite 12 in the constellation comes within range or, depending on the destination it may forward the message by one of the relay means described below.

Distributed Linked Relay Stations

The relay stations 34 are distributed internationally in a pattern of locations on the Earth E which maximize coverage and minimize time to forward messages and data between any two user terminals

212. To reduce the time of delivery of message traffic even further, the distributed relay stations 34 may be linked together in several ways as depicted in FIG. 20.

In one alternative embodiment, a group of Equatorial relay stations 224, eight to twelve in number, are spaced along the Equator 16. These Equatorial relay stations 224 are used to store and forward traffic sent from satellites travelling in opposite directions in orbits 210 inclined by fifty to sixty degrees. This method is similar to the method used by the polar relay stations 34 to store and forward traffic from satellites in more steeply inclined or polar orbits 60.

In another alternative embodiment, relay stations 34 are linked through a geostationary communication satellite 218 by use of very small aperture terminals (VSAT's). In a variation of this embodiment, large low Earth orbit communications satellites may be used for these linkages in place of the much higher altitude geostationary satellites 218.

In still another alternative embodiment, relay stations 34 are linked through public, switched telephone networks 220, which are available in most of the developed world. To provide a great deal of system reliability, certain relay stations 34 can function as a message-forwarding station, or a network operation control center (NOCC). For example, if the message held at a relay station in New York is addressed to an addressee in California, the message may be forwarded by the public, switched telephone network 220.

The ability of a relay station 34 to select among alternative network means to forward messages enables the provision of an "auction protocol" for users. In its initial communication with a user, the satellite 12 "announces" the level of traffic it is currently accepting. The level of traffic is varied from, say level one, the fastest and most expensive mode of delivery to the next fastest and less expensive mode of delivery and so on until the slowest and least expensive level is reached. A user can, therefore, elect to send a message at the highest level of service, or wait for a cheaper, lower level of service. This protocol is further discussed in the section describing the user terminal-satellite downlink 216 protocol.

The satellite system (52, 54, 56, 58, 62, 64a, 64b) will be distinguished by the range of services offered, the low cost of its service options relative to those offered by similar proposed service providers and its high spectral efficiency. The types of services provided by the present invention include tracking and monitoring for the transportation industry, monitoring of remote assets or site locations, such as vehicles, boats and vacation homes or remote utility equipment, E-mail, paging and emergency services.

Telecommunication Frequencies and Spectrum

The present invention has been designed from the outset to make efficient use of the scarce spectrum available. Table A3 below summarizes the total spectrum available in the U.S. for this type of service, resulting from the allocations made at WARC-92 and in the Commission's Order allocating spectrum for the NVNG MSS.

TABLE A3

MSS Frequency Allocations Below 1 GHz	
Earth-to-Space	Space-to-Earth
148.000 to 150.050 MHz	
	137.000 to 138.000 MHz
399.900 to 400.050 MHz	
	400.150 to 401.000 MHz

This amounts to a total of 2.2 MHz for the Earth-to-space links (uplink) and 1.85 MHz for the space-to-Earth links (downlink). However, parts of this available spectrum are only allocated on a secondary basis to the MSS service, and even the primary MSS allocations are allocated on a co-primary

basis to other services, such as Fixed, Mobile, Meteorological-Satellite, Space Operation, Space Research and Meteorological Aids. The ability of the system to effectively and efficiently share the spectrum in this type of environment is therefore of paramount importance.

FIG. 21 graphically depicts the frequencies and bandwidths at which the satellite system will communicate messages. The TSUs and the RSUs will operate in the 148-149.9 MHz band and the TSD and RAD will operate in the 137.175-137.825 MHz band. All of the links will carry "packetized" digital data. Network packets will be used for resource request and assignment, and other network control functions. Monitoring packets will be used for monitoring applications. Text packets will be used for message applications. The Text packet length will be selected to comply with footnote US323 to the Frequency Allocation Table, 47 C.F.R. .sctn.2.106. Footnote US323 requires that, in the 148-149.9 MHz band, single transmissions from individual Earth stations may not exceed 450 msec in duration (4160 bits/9.6 kbps=433.3 msec).

Frequency assignments for the satellite downlinks (35a, 216) will be in four segments. That is, for all satellites 12 in a given orbital plane 210, the frequencies will be the same. Because of no overlap in the radio beam footprints of the six satellites 12 travelling in each fifty degree inclined orbit 210, there is no interference between these satellites 12. Ground control of frequency assignments will prevent interference between satellites 12 in these orbits and satellites 12 in Equatorial orbit 14.

In this embodiment 64a, since satellites 12 in sectors of orbits 210 on the same side of the Earth E will be transmitting on the same frequencies without interference from other satellites 12, it is possible to reduce the bandwidth of the TSD downlink signal spectrum to one-fourth of that used in some other embodiments.

Each satellite 12 in this embodiment 64a has six receive channels. Other embodiments may require up to fifteen receive channels. The method of channel assignment to the user terminal transmitters is discussed below in the Section entitled "Dynamic or Adaptive Channel Assignment".

Data Transmission

FIG. 22 is a packet structure diagram 225 showing the information contained in certain fields. For example, the first field may contain the address of the recipient. The second field may contain the "hop" count or how many relays have occurred to the current time. The next field may contain the sequence count or frame number. The fourth field may contain the sender's identification, and so on. Table A4 below describes the packet structures.

TABLE A4

Packet Structures	Network	Monitoring	Text
Data	12 bytes	80 bytes	500 bytes
Overhead	20 bytes	20 bytes	20 bytes
Total	32 bytes	100 bytes	520 bytes

The user terminal-satellite link bit error rate objective is 10.sup.-6 and the relay station-satellite link bit error rate objective is 10.sup.-8. The packet overhead bits allow for synchronization, parity check, sequencing, status, and addressing and routing. Forward error correction coding is employed in the store-and-forward system. Raw data bits are mapped into symbols in a manner which results in each symbol containing information about multiple bits. Lost data bits can therefore be recovered.

Each satellite will support fifteen TSUs 214 at a data transmission rate of 9.6 kilobits per second (kbps), one TSD 216 at a data rate of 24 kbps, one RSU 35a at a data rate of 50 kbps, and one RSD 35b at a data rate of 50 kbps. Thus, the user terminals 212 may transmit at 9.6 kbps and receive at 24 kbps. The TSU

bandwidth is 15 Kilohertz (KHz) and the TSD bandwidth is 28.8 KHz. The relay stations 34 will transmit and receive at 50 kbps and have a bandwidth of 50 KHz for the uplink and 60 KHz for the downlink. While the nominal TSU transmission data rate is 9.6 kbps, lower cost user terminals 212 are possible if lower data rates are used. Therefore, data rates as low as 300 bps will be available. For example, a user terminal 212 might transmit at standard data rates of 9600, 4800, 2400, 1200, 600 or 300 bps. Besides the low cost and availability of equipment capable of the lower transmission rates, battery power requirements are reduced substantially which makes this method attractive for hand held or periodic reporting user terminals 212. For example, burst power for a 300 bps signal is only about 20 milliwatts compared to about five watts for a 9.6 kbps signal.

The system will use a combination of random access and frequency division multiplexing (FDM) for the TSUs 214 and time division multiplexing (TDM) for the other links. FDM is preferred for the TSUs 214 because it does not require high burst power transmissions from the user terminals 212 that would be required for a single wideband TDM channel. TDM is preferred for the other links because it allows for the use of efficient saturated power amplifiers in the satellites 12 and relay stations 34, 61, 65. Back-off is not required to control intermodulation levels since there will be only a single RF carrier in these links.

All of the links will use differentially encoded offset-quadraphase shift keying (OQPSK) modulation filtered for 50% excess bandwidth in combination with rate 7/8, constraint length 7, convolutional coding. This format has been selected because of its high combined modulation/coding efficiency of 1.17 bits/sec/Hz.

However, frequency shift keying (FSK) modulation is also used on a time-shared basis to support low-cost user terminals 212. A user terminal 212 can use an FSK demodulator absorbing only "trickle" power, i.e., low current, while waiting for a satellite signal to appear. An FSK signal can be sent at reduced data rate, for example 6 kbps, because of a smaller portion of spectrum occupied by an FSK modulated signal. A ground station looks for an ID code in the FSK mode. It can then, if desired, turn on the OQPSK keying demodulator and operate at a faster rate.

The downlink (35b, 216) signal is partitioned into 500 millisecond (msec) frames. Initially, signals are FSK modulated. Later signals in the 500 msec frame may be FSK or OQPSK modulated depending on the demand. The network operation control center NOCC varies the time-sharing between FSK and OQPSK modulation depending on traffic load.

The uplink (35a, 214) signals are OQPSK modulated, although the use of FSK modulation and lower data rates offer some cost reduction.

The required channel bandwidths are a function of the data rate, the spectral efficiency of the modulation and coding, the user terminal or relay station and satellite frequency stability, the uncompensated Doppler shift and the channel filtering. The required channel bandwidths are summarized in Table A5.

TABLE A5

Channel Bandwidth Requirements

	User Term. Uplink	User Term. Downlink	Relay Sta. Uplink	Relay Sta. Downlink
Signal Bandwidth	8.2 KHz	19.1 KHz	42.8 KHz	42.8 KHz
+/- Frequency	0.6	0.3	0.3	0.3
+/- Doppler	6.2	5.6	6.2	16.6

Total	15	25	49.3	59.7
Channel Bandwidth				
	15 KHz*	25 KHz	50 KHz	60 KHz

*A single user terminal requires 15 KHz, therefore fifteen\ simultaneous users require 225 KHz bandwidth.

To implement the "auction" protocol, the satellite 12 indicates what level of traffic it is accepting within the 500 ms frame of the first burst of dam. User terminals wishing to send that level of traffic will do so. Terminals having lower levels of traffic will wait. The auction protocol sequentially lowers the level of traffic it is accepting until all users desiring the highest to the lowest level of service are accommodated.

The present invention uses a combination of random access and frequency division multiplexing (FDM) for the TSUs and time division multiplexing (TDM) for the other links. FDM is preferred for the TSUs because it does not require high burst power transmissions from the transceivers that would be required for a single wideband TDM channel. TDM is preferred for the other links because it allows for the use of efficient saturated power amplifiers in the satellites and relay stations. Back-off is not required to control intermodulation levels since there will be only a single RF carrier in these links.

Dynamic or Adaptive Channel Assignment

FIG. 24 depicts a functional block diagram of the satellite subsystems which includes the RF communications subsystem 230. The satellite's communications payload 280 which includes the RF communications subsystem 230 a computer subsystem and a frequency reference, is shown in block diagram in FIG. 24. The satellite 12 monitors the pool of frequencies in the 148.0 to 149.9 MHz band and assigns channels to user terminals 212 as available. A band scanning receiver contained in the RF communications section 230 of the satellite 12 is a digital spectrum analyzer. The receiver scans the TSU band each 0.5 seconds for TSU signals. The computer subsystem projects channel usage for the next 0.5 seconds and in the first burst of the protocol, instructs a calling user terminal 212 which channel to use. An algorithm is used to make the channel projection based on the half-second sample history.

Communications Payload Description

A functional block diagram of the satellite's communications payload 280 is shown in FIG. 24. The antenna subsystem converts the free space propagated waveforms into RF signals for processing by the user terminal-satellite uplink (TSU) receiver, the relay station-satellite uplink (RSU) receiver, and the band scanning receiver. It also converts the RF signals from the user terminal-satellite downlink (TSD) transmitter and the relay station-satellite downlink (RSD) transmitter into free space propagated waveforms. Two transmitting antennas are used, one for the TSD links and the other for the RSD links. This will eliminate the combining loss that would occur if the TSD and RSD signals were radiated from the same antenna.

The spacecraft antennas will be shaped to partially compensate for the changing free space propagation loss due to the range variation that occurs between the time the satellite appears at the lowest elevation angle and the time it is directly overhead. This maximum variation in path loss corresponds to about 7.5 dB in propagation loss. As a result, the preliminary spacecraft antenna design has a gain of -2 dBi in the nadir direction and +5.5 dBi at a fifteen degree grazing angle. The satellite antenna gain pattern is shown in FIG. 25. The satellite antennas will be left-hand circular polarized, though right-hand polarization is also possible.

The TSU receiver will downconvert, demodulate, and decode the uplink signals received from the transceivers. The TSU receiver will provide the demodulated packets to the computer subsystem at 57.6 kbps for processing. The RSU receiver will perform the same functions for the RSU channel.

The TSD transmitter will accept packetized data from the computer subsystem at 24 kbps, encode and modulate the data, upconvert it to the transmit channel frequency, and provide 20 watts of transmit

power using a solid-state power amplifier (SSPA). The RSD transmitter will perform the same functions for the 50 kbps RSD data using a 2.5 W SSPA.

The band scanning receiver will scan the potential transceiver-satellite uplink channels in the 148-149.9 MHz band in 15 KHz increments to determine channel activity and signal levels. The six least active channels will be identified twice per second and this information will be broadcast to the transceivers.

The frequency reference subsystem 326 will provide stable frequency and time signals to the other functions. The computer subsystem 324 will process all of the received packets, store them in memory, and retransmit them as required. It also will use the data from the band scanning receiver to make TSU channel assignments.

Key communications payload 280 parameters are shown in Table A6.

TABLE A6

Key Satellite Communications Payload Parameters	
Antenna	
Nadir Gain	-2 dBi
Edge of Coverage Gain	5.7 dBi
Edge of Coverage Beamwidth	114 degrees
Polarization	LHC
TSD Transmitter	
Frequency Band	137.175-131.825 MHz
Number of Channels	1
Transmit Power	25 W
99% Power Channel Bandwidth	17.1 KHz
Data Rate	24 kbps
RSD Transmitter	
Frequency Band	137.175-137.825 MHz
Number of Channels	1
Transmit Power	15 W
99% Power Channel Bandwidth	42.8 KHz
Data Rate	50 kbps
TSU Receiver	
Frequency Band	148-149.9 MHz
Number of Channels	15
Channel Bandwidth	15 KHz
Per Channel Data Rate	9.6 kbps to 300 bps, variable
Noise Figure	4 dB
RSU Receiver	
Frequency Band	148-149.9 MHz
Number of Channels	1
Channel Bandwidth	50 KHz
Per Channel Data Rate	50 kbps
Noise Figure	7 dB
Band Scanning Receiver	
Frequency Band	148-149.9 MHz
Number of Channels	1
Channel Bandwidth	

	2.5 KHz
Noise Figure	4 dB
Frequency Reference	
Frequency Stability	
	0.1 PPM over environment and time
Computer	
Memory	16 Mbytes

The TSD and RSD transmitter filters response characteristics are shown in FIGS. 26 and 27 respectively. These filters protect the radio astronomy service in the 150.05-153 MHz and 406.1-410 MHz bands from harmful interference by limiting spurious emissions in those bands.

Because the spacecraft will be processing satellites, it will be impossible for signals received from sources outside of the network to cause output signals different from intended output signals.

V. User Terminals

As illustrated by FIG. 28, the present invention will provide a family of low-cost user terminals or transceivers to support a variety of different applications. The heart of these transceivers is the modem module 300. The modem 300 will be small, less than ten cubic inches, and capable of battery operation. It will be available in pocket-sized, desktop, and vehicle mounted transceiver configurations. Application-specific transceiver configurations will be constructed by combining the modem module 300 with other modules, as shown in FIG. 28. A schematic illustration of the modem module 300 is provided in FIG. 29. Table A7 provides examples of how these modules might be combined for different applications, although other combinations are possible. Prices for a basic transceiver are expected to be under US $500.

TABLE A7

Possible Module Combinations for Different Applications

Applications	Leo One Modem	Battery Pack	Whip Antenna	AC Adapter	Expanded Memory	GPS	Parallel Interface	Palm-top PC
Status Monitoring	X	X	X				X	
Vehicle Tracking	X					X		
Paging	X	X	X					
E-Mail	X	X	X		X			X
Security Monitoring and Control	X	X	X				X	
Emergency Alerting	X		X	X				

User Terminal Technical Parameters

The modem module 300 will interface directly with an antenna 314. In most applications, the standard antenna 314 will be a normal-mode helix similar to those used with conventional hand-held VHF transceivers. In vehicle mounted applications, the standard vehicle FM radio antenna or an enhanced replacement will be used.

The TSD receiver 320 will downconvert, demodulate, and decode the 24 kbps satellite downlink channel. The TSU transmitter 322 will accept packetized data from the computer subsystem 324 at rates variable from 9.6 kbps to 300 bps, encode and modulate the data, upconvert it to the transmit channel frequency, and provide about 5 W of transmit power. The frequency reference subsystem will provide stable frequency and time signals to the other functions. The computer subsystem will process the received packets and make the data available to the other modules or directly to the subscriber via an RS-232 port. The computer 324 will receive data to be packetized and uplinked from other modules or directly from the subscriber via an RS-232 port.

The key user terminal 212 technical parameters are summarized in Table A8. User terminals 212 are designed to be incapable of radiating in the 108-137 MHz bands.

The satellites have high velocities relative to a fixed terminal on the Earth's surface resulting in large Doppler shifts on the transmitted and received RF carriers. In the 148-149.9 MHz uplink band, the worst case Doppler shifts will be 2.2 KHz and in the 137-138 MHz downlink band they will be 2.0 KHz. The user terminals will track the user terminal-satellite downlink Doppler, scale the measured value by the uplink/downlink frequency ratio, and pre-compensate the user terminal-satellite uplink transmissions such that the signals are received at the satellite with no apparent Doppler shift. This will virtually eliminate frequency acquisition time at the satellite. Even an inexpensive user terminal frequency reference will reduce the apparent Doppler to less then 300 Hz. The maximum user terminal transmit power of about 5 W in conjunction with the low, 1% maximum, duty cycle will ensure that the user terminals will comply with all relevant radiation exposure safety standards.

TABLE A8

Key User Terminal Parameters	
Antenna	
Pattern	Non-Directional
Polarization	Vertical
Transmitter	
Frequency Band	148-149.9 MHz
Channel Bandwidth	15 KHz
Number of Active Channels	1
Doppler Pre-Compensation	.+-.2.2 KHz
Transmit Power	5 W
Burst Duration	450 msec
Burst Spacing	15 seconds
Duty Cycle	9 seconds every 15 minutes
99% Power Bandwidth	8.2 KHz
Modulation	OQPSK
Coder	Convolutional r = 7/8, K = 7
Data Rate	9.6 kbps to 300 kbps
Receiver	
Frequency Band	137:175-137.825 MHz
Channel Bandwidth	25 KHz
Number of Active Channels	1

Doppler Pull-In Range	.+-.2.0 KHz
Demodulation	OQPSK & FSK
Decoder	Soft Decision Viterbi r = 7/8, K = 7
Data Rate	24 kbps
Noise Figure	7 dB
Implementation Loss	2 dB
Frequency Reference	
Frequency Stability	1.0 PPM over environment and time

User Terminal and Relay Station Antenna Gain Patterns

A typical user terminal 212 antenna gain pattern is shown in FIG. 30. A typical relay station 34 antenna gain pattern is shown in FIG. 32.

Relay Station Technical Parameters and Operation

A relay station 34 functional block diagram 330 is shown in FIG. 31. The RSD receiver 334 will downconvert, demodulate, and decode the 50 kbps satellite downlink channel and provide the demodulated packets to the computer subsystem for subsequent processing. The RSU transmitter 332 will accept packetized data from the computer subsystem 336 at 50 kbps, encode and modulate the data, upconvert it to the transmit channel frequency, and provide 1.8 W of transmit power.

The frequency reference subsystem 338 will provide stable frequency and time signals for the other functions. The computer subsystem 336 will perform the packet and network overhead functions including packet routing and billing. It will control the open loop pointing of the relay station antenna to acquire and follow the satellites. In addition, it will process Doppler frequency measurements of the satellite signals to refine their orbital estimates.

The TT&C subsystem 340 will decode and process the telemetry data packets from the satellites 12 and generate and encode command packets for transmission to the satellites. All of the TT&C data will be encrypted to prevent unauthorized control of the satellites.

The NOCC subsystem 342 will allow for control of the constellation. The NOCC functions will include resolving overlap conflicts by commanding one of the overlapping satellites to cease operation during the overlap and monitoring constellation traffic levels.

The key relay station technical parameters are summarized in Table A9.

TABLE A9

Key Relay Station Technical Parameters	
Antenna	
Operating Frequency	137-138 MHz & 148-149.9 MHz
Polarization	LHC
Gain	16 dBi
Half Power Beamwidth	22.5 degrees
Receiver	
Frequency Band	137.175-137.825 MHz
Channel Bandwidth	50 KHz
Number of Channels	1
Doppler Shift	2.1 KHz

Demodulation	Differential OQPSK
Decoding	Soft Decision Viterbi, r = 7/8, K = 7
Data Rate	50 kbps
Noise Figure	4 dB
Implementation Loss	2 dB
Transmitter	
Frequency Band	148-149.9 MHz
Channel Bandwidth	50 KHz
Signal Bandwidth (99% power)	71.3 KHz
Number of Channels	1
Transmit Power	1.8 Watts
Modulation	Differential OQPSK and FSK
Coding	rate-7/8, constraint length 7 convolutional
Data Rate	50 kbps
Frequency Reference	
Frequency Accuracy	0.1 PPM over environment and time

The relay stations 34 will poll the satellites 12 to initiate data transfer. The relay stations 34 will predict when each satellite will appear above the minimum elevation mask angle and use open loop pointing of the relay station 34 antenna to acquire and follow the satellite 12. The relay stations 34 will estimate the satellite signal Doppler shift to minimize acquisition time. The relay stations 34 will use Doppler frequency measurements of the satellite signals to refine their orbital estimates.

The relay station-satellite uplink (RSU) and relay station-satellite downlink (RSD) signals are partitioned into 500 msec frames. Each frame will be divided into two time slots. The first time slot will be reserved for network control (Network packets). The remaining time slot will allow for the transfer of Text packets, Monitoring packets, or some combination. All packet exchanges will be acknowledged by the recipient using Network packets. The relay station 34 and the satellite will send at least one Network packet in the network control time slot until the relay station signs off.

VI. Satellite & Orbital Configurations for Preferred & Alternative Embodiments

FIGS. 33 and 34 are graphs which reveal VHF antenna design trades for a 100 W transmitter for altitudes of 1,100 km and 1,856 km, respectively. FIGS. 35 and 36 present graphs which reveal UHF antenna design trades for a 100 W transmitter for altitudes of 1,100 km and 1,856 km, respectively. FIG. 37 shows mean and maximum response times for four satellites at different altitudes and latitudes. FIG. 38 exhibits the percent of time that a range of latitude is covered by four satellites moving in Equatorial orbits. FIG. 39 depicts mean and maximum response times for six satellites at various latitudes. FIG. 40 shows the percent of time that a range of latitude is covered by six satellites moving in Equatorial orbits. FIG. 41 displays mean and maximum response times for eight satellites at various latitudes. FIG. 42 portrays the percent of time that a range of latitude is covered by eight satellites moving in Equatorial orbits. FIG. 43 supplies a graph which illustrates the altitude required for thirty-five degree latitude coverage at a specified elevation angle. FIGS. 44, 45 and 46 provide schematic block diagrams of electronics that are utilized to implement one of the embodiments of the invention. FIG. 44 shows the VHF only payload, FIG. 45 shows dual VHF and UHF downlink modules and FIG. 46 shows a combined VHF and UHF payload diagram. FIG. 47 shows how satellites transfer dam from an Equatorial to an inclined orbit via a crosslink through a relay station. FIGS. 48, 49 and 50 are diagrams showing satellite footprints for satellites orbiting at 800 km, 1,100 km and 1,852 km altitudes. FIGS. 51, 52 and 53 portray mean and maximum response times for satellites orbiting at 800 km, 1,100 km and 1,852 km altitudes.

VII. Other System Services

Besides those services identified above, other system services can be easily provided by the present invention. Some of these are described below.

Seaborne Radio Beacon System

FIG. 54 shows schematically a radio beacon system 350 for monitoring sea environment and tracking data with deployed buoys 352 transmitting data through the satellite constellation-to-ground terminal links 214, 35b, 220 of this invention. A low cost buoy 352 is fitted with environmental and weather instrumentation 356 and/or an energy sensing device such as an underwater listening device 354. The buoy also contains a position-determining device such as LORAN or Global Positioning System (GPS). An on-board user terminal 212 sends buoy-collected environmental, sensed energy, tracking and positioning digital data through the TSU 214 to the satellite 12. The data is then disseminated to a receiving party through a relay station 34 and terrestrial communication links 220 so as to minimize transmission time. As an example, oil spills can be tracked by dropping such a buoy 352 into the slick from an aircraft.

Interactive Television Return Link

FIG. 55 is a schematic depiction of an interactive television system 360 which uses a return link from a viewer to a TV broadcaster through the satellite constellation of this invention. A television signal 361 from a direct broadcasting satellite such as C band or Ku band devices is captured by an integrated antenna system 365 consisting, for example, of a small dish antenna 364 which receives the TV satellite signal and an integrated whip antenna 362 for communication with a satellite 12 operating in accordance with the present invention. The user views the television program on a TV screen 372 which is derived from a television signal 361 in a TV converter 366, carried through coaxial cable 363. The converter 366 is integrated with a modem 300 and connected to a personal computer or other digital data input device 368. The user sends his interactive responses to a broadcaster by entering them in the computer 368 which is converted to a TSU signal 214 by the modem 300 and transmitted as digital data to a satellite 12 for delivery to the broadcaster.

FIG. 56 is a schematic depiction 380 of the return links from a viewer of a direct broadcasting satellite 382 TV broadcast 361 through the terminal-satellite uplink 214, satellite constellation-to-ground terminal downlinks 35b of this invention and terrestrial based data networks 220. It is also possible for a broadcaster or intermediary to confirm the receipt of the user's data by returning a message through the satellite constellation-to-ground terminal links 35b and the terminal-satellite downlink 216.

Connectivity of Office or Factory Data to Other Systems from Within a Structure

FIG. 57 is a schematic diagram of a system 390 revealing a method of providing connectivity to other systems from movable devices or devices with low rate data inside a building 392 or other structure which shields the user's radio signal from the satellite. The data input devices 391 may be pagers, computers, facsimile machines, copy machines, etc. A non-licensed personal communication service (PCS) 394 is coupled to a data input device 391 through a coupling device 396. The coupling device 396 may be a PCMCIA, RS232, RJ11 or other connector. Such a personal communication system is limited to low power, short range transmitters. The data is transmitted by the PCS to a nearby, integrated terminal 398 which contains a PCS transceiver coupled to a LEO One USA.TM. modem 300. An antenna 399 is connected to the modem 300. This system offers a user 395 two-way data communication even though he or she is shielded in a windowless structure or perhaps underground. The modem 300 retransmits the data through the antenna 399 as a TSU signal 214 to a passing satellite 12 of the invention. The data may be forwarded by the satellite 12, such relay stations 34, VSAT links (222) and PSTN (220) as minimizes transmission time. Return messages are received from a satellite 12 via the TSD 216 and relayed through the unlicensed PCS 394. The integrated terminal 398 may be powered by a solar panel 397. Such systems 390 are particularly useful in very old structures, third-world locations and other situations where direct wiring from the data input device 391 to the modem 300 is difficult or expensive to install. The system 390 also has use where the data input device 391 is movable or portable.

Time Synchronization Broadcasts

Many devices, including consumer products and industrial control devices require or make use of time information. Electric clocks can drift or be delayed by power outages. Currently, a time standard is supplied world-wide by The National Bureau of Standards through short wave radio stations WWV. The recipient must have a short wave receiver and substantial antenna to receive these signals reliably. For automatic synchronization, the WWV signal must be decoded and applied to a device through sophisticated electronics means which would be much too expensive for the average consumer and the average industrial user.

Satellites 12 orbiting in the constellation of this invention can transmit narrow data messages at regular intervals that can be used to synchronize clocks to the National Bureau of Standards clock anywhere in the world through a relatively inexpensive user terminal. A satellite 12 would broadcast Universal Coordinated Time (UTC) signals which are converted to local time by a customer setting the appropriate time zone into his system.

Monitoring Remotely Installed Devices or Machines for Non-Functioning or Needed Repair

Almost any type of device or machine remotely installed from a responsible owner's home office can be monitored for non-functioning by means of an inexpensive user terminal 212 connected to the device to be monitored and transmitting the data through a satellite 12 orbiting in the constellation of this invention. This type of monitoring reduces or eliminates the need for personnel to patrol the devices or machines. For example, remote boulevard lights can be fitted with a switch which indicates failure of the lamp. A transmitter reacts to the operation of the switch by sending a packet containing a short code which identifies the location of the boulevard light. Other similar uses are possible: monitoring overnight mail drops for packages to be picked up or for replenishing supplies; monitoring vending machines for replenishing stock; monitoring aircraft warning lights on tall buildings or hazards, where failure of these lights can result in significant financial penalties to the owner, etc.

Wide Area Broadcast of Updated Information

Market data on a near-real time basis can be disseminated on a global basis through satellites 12 orbiting in the constellation of this invention. Field sales representatives can receive, for example, updated price adjustments and monetary exchange rates. Brokers can receive updated securities quotes from world-wide markets, interest rates and commodity prices. Other users can receive updated weather, sports information, etc. While the transmission of these data is well known, the use of the satellite system of the present invention presents a novel, unique and efficient method of reaching users on a regional, national and international basis, leading to a more competitive business.

World-Wide Synchronization of Clocks to Universal Coordinated Time (UTC)

Coordination of clocks to Universal Coordinated Time can be accomplished by obtaining Universal Coordinated Time (UTC) signals provided by the National Bureau of Standards, through a communication link (35a, 220) and broadcasting the UTC signals through a plurality of satellites (12). UTC signals are received at the user terminals (212) and are coupled to a clock in a local clock system. The local clock system is capable of responding to the broadcast UTC signals. The UTC signals are passed to the local clock system and clocks in the system are synchronized to the UTC signals.

CONCLUSION

Although the present invention has been described in detail with reference to a particular preferred embodiment, persons possessing ordinary skill in the art to which this invention pertains will appreciate that various modifications and enhancements may be made without departing from the spirit and scope of the claims that follow. The various orbital parameters, satellites altitudes and populations and locations of the user terminals and relay stations that have been disclosed above are intended to educate

the reader about preferred embodiments, and are not intended to constrain the limits of the invention or the scope of the claims. The List of Reference Characters which follows is intended to provide the reader with a convenient means of identifying elements of the invention in the specification and drawings. This list is not intended to delineate or narrow the scope of the claims.

LIST OF REFERENCE CHARACTERS	
FIG. 1	
10	Illustration of one embodiment of invention using six satellites in Equatorial orbit
12	Satellite
14	Equatorial orbit
16	Equator
18	30 degrees North latitude
20	30 degrees South latitude
E	Earth
FIG. 2	
22	Illustration of one embodiment of invention using fourteen satellites in Equatorial orbit
FIG. 3	
24	Satellite body
25	Solar panels
26	Helical antennas
28	Inter-satellite link antennas
FIGS. 4 & 5	
30	Coverage areas on ground between 30 degrees North & 30 degrees South
32	Coverage areas on ground between 30 degrees North & 30 degrees South
FIG. 6	
34	Relay stations located on ground within 30 degrees of Equator
FIGS. 7, 8 & 9	
36	Illustration of footprints from 6 satellites in Equatorial orbit at 1,852 km
38	Footprint from one of 6 satellites at 1,852 km
40	Latitude
42	Longitude
44	Illustration of footprints from 8 satellites in Equatorial orbit at 1,852 km
46	Footprint from one of 8 satellites at 1,852 km
48	Illustration of footprints from 14 satellites in Equatorial orbit at 1,852 km
50	Footprint from one of 14 satellites at 1,852 km
FIG. 10	
52	Diagram of satellites in Equatorial orbit using ground stations to relay data
FIG. 11	
54	Diagram of satellites in Equatorial orbit using inter-satellite links to relay data
55	Inter-satellite links
FIG. 12	
56	Diagram of satellites in Equatorial orbit using ground stations and inter-satellite links to relay data
FIG. 13	
58	Diagram of satellites in Equatorial and polar orbits with Equatorial and polar relay stations
60	Polar orbits
61	Polar relay station
65	Relay stations at middle latitudes
NP	North Pole
TR1	Transfer 1
TR2	Transfer 2

TR3	Transfer 3
TR4	Transfer 4
TR5	Transfer 5
TR6	Transfer 6
FIG. 14	
62	Illustration of combined fleet of satellites in Equatorial and 60 degree inclined orbits
63	Orbits inclined at 60 degrees
FIGS. 15A & 15B	
12	Satellite
14	Equatorial orbit
34	Relay stations within 30 degrees of Equator
64a	Illustration of combined fleet of satellites in Equatorial orbit and 50.degree. inclined orbits
64b	Illustration of combined fleet of satellites in Equatorial orbit, polar orbits and inclined orbits
65	Relay stations at middle latitudes
210	Fifty degree inclined orbit
FIG. 16	
34	Relay stations
68	Elevation angle
E	Earth
FIG. 18	
12	Satellite
16	Equator
210	Fifty degree inclined orbit
E	Earth
NP	North pole
SP	South pole
FIGS. 19, 20 & 21	
12	Satellite
34	Relay stations
35a	Relay station uplink (RSU)
35b	Relay station downlink (RSD)
212	User terminal
214	Terminal-to-satellite uplink (TSU)
216	Terminal-to-satellite downlink (TSD)
218	Geostationary communications satellite
220	Public, switched telephone network (PSTN)
222	Satellite very small aperture terminal (VSAT) links
224	Equatorial relay stations
FIG. 22	
225	Packet structure diagram
FIG. 23	
230	RF communications subsystem
240	Tracking, telemetry & control computer
250	Attitude determination and control subsystem
260	Electric power subsystem
270	Thermal control subsystem
FIG. 24	
280	Communications payload block diagram
FIG. 28	
300	Modem module
302	Expanded memory
304	Parallel interface
306	AC adapter
308	Palmtop personal computer
310	Global positioning system
312	Battery pack
314	Whip antenna
FIG. 29	
300	Modem module
314	Antenna

320	Terminal-to-satellite downlink (TSD) receiver
322	Terminal-to-satellite uplink (TSU) transmitter
324	Computer subsystem
326	Frequency reference
FIG. 31	
330	Relay station functional block diagram
332	Relay station-to-satellite uplink (RSU) transmitter
334	Relay station-to-satellite downlink (RSD) receiver
336	Computer subsystem
338	Frequency reference
340	Tracking, telemetry and control subsystem
342	Network operation and control center subsystem
344	Public switched telephone network (PSTN) interface
FIGS. 54, 55, 56 & 57	
12	Satellite
34	Relay stations
35a	Relay station uplink (RSU)
35b	Relay station downlink (RSD)
212	User terminal
214	Terminal-to-satellite uplink (TSU)
216	Terminal-to-satellite downlink (TSD)
220	Public switched telephone network (PSTN)
300	Modem module
350	Schematic illustration of a user service employing deployed buoys for sending remote data
352	Deployed buoy
354	Underwater listening device
356	Environmental & weather instruments
360	Schematic depiction of an interactive television system using a return link from a viewer to a TV broadcaster through the satellite constellation of this invention.
361	Television signal provided by broadcasting satellite
362	TSU whip antenna
363	Coaxial cable from antenna to video and data input equipment
364	TV satellite antenna
365	Integrated antenna system
366	TV converter/tuner and modem for communicating with the satellite constellation used in this invention
368	Data input device, e.g., personal computer
372	TV receiver
380	Schematic depiction of the return link from a viewer of a satellite TV broadcast through the satellite constellation-to-ground terminal links of this invention and terrestrial based data networks
382	TV broadcasting satellite
390	Schematic depiction of a method of providing connectivity to movable devices or devices with low rate data inside a building which shields the user's radio energy from the satellite
391	Data input device, e.g., personal computer, handy-talky, pager, etc.
392	Building shielding user from satellite
394	Personal communication system (PCS) within building
395	User
396	Interconnection device; e.g., PCMCIA, RS232 or other modem
397	Solar panel
398	Integrated pcs transmitter/receiver and TSU transmitter/TSD receiver
399	TSU/TSD antenna